

**Application for Letters Patent
of the United States**

Inventor:

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Title of Invention:

METHODS OF PREPARING HOLOGRAMS

To All Whom It May Concern:

*The following is a specification of the
aforesaid Invention:-*

1 TITLE

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3 Methods of Preparing Holograms

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5 CROSS REFERENCE TO RELATED APPLICATION(S)/CLAIM OF PRIORITY

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7 This application is a continuation-in-part of and claims benefit of co-pending
8 U.S. Nonprovisional Application Serial No. 09/749,984 filed December 27, 2000, which
9 in turn is a continuation of U.S. Nonprovisional Application Serial No. 09/111,990 filed
10 July 8, 1998, now issued as U.S. Patent No. 6,229,562, which in turn claims benefit of
11 U.S. Provisional Application Serial No. 60/051,972 filed July 8, 1997. The
12 aforementioned patent applications and patent are hereby incorporated by reference in
13 their entirety herein.

14

15 STATEMENT REGARDING FEDERALLY SPONSORED RESEARCH OR
16 DEVELOPMENT

17

18 Not applicable.

19

20 REFERENCE OF AN APPENDIX

21

22 Not applicable.

23

1 BACKGROUND

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3 1. Field of the Invention

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5 This invention relates to methods of preparing holograms to be used in a
6 SYSTEM AND APPARATUS FOR THE RECORDING AND PROJECTION OF
7 IMAGES IN SUBSTANTIALLY 3-DIMENSIONAL FORMAT.

8

9 2. Brief Description of Related Art

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11 U.S. Patent No. 6,229,562, that is incorporated herein by reference (hereinafter
12 referred to as "Patent '562") discloses and claims a SYSTEM AND APPARATUS FOR
13 THE RECORDING AND PROJECTION OF IMAGES IN SUBSTANTIALLY 3-
14 DIMENSIONAL FORMAT. The invention described therein derives from the principles
15 of holography and/or integral photography. Patent '562 first discloses a basic principle of
16 magnification and projection. This principle permits magnification and projection of 3-
17 dimensional images uniformly in all directions, thereby overcoming drawbacks in the
18 prior art. Based upon this principle, cameras are described, in their various embodiments,
19 that photograph a scene and retain the 3-dimensional information therein. An editor is
20 also described that would edit integral photographs and holograms containing the 3-
21 dimensional information from the photographed scene. In addition, a theater is designed
22 to project the magnified 3-dimensional scene that was photographed, upon a large screen

1 to be viewed by an audience. Further, the projectors and screens are described in their
2 various embodiments.

3 Within some of the embodiments of the camera and projector, specially prepared
4 holograms are used as optical elements therein. Use of these holograms affords the
5 advantage of being able to replace complex, bulky, difficult to manufacture, and
6 expensive conventional optical elements needed to produce certain types of images
7 during photography, magnification, and projection. In addition, some of the
8 embodiments of the screen are themselves holograms. Unlike conventional projection
9 screens used in current theaters, the screen described in Patent '562 is an active optical
10 element that, when combined with the projection optics, causes light waves to emanate
11 from the screen into the theater that are the same as though the 3-dimensional scene were
12 real. Therefore, the viewing audience should not be able to perform any visual test to
13 determine whether or not the projected 3-dimensional scene truly exists. The use of a
14 specially developed holographic screen affords the advantage of replacing more
15 conventional optical components used in screen fabrication.

16 In view of the above, it is therefore an object of the invention to provide methods
17 of preparing the various holograms used as optical elements in the camera, projector, and
18 screen embodiments described in Patent '562.

19 20 SUMMARY OF THE INVENTION

21
22 The object of the invention as well as other objects which shall be hereinafter
23 apparent are achieved by the METHODS OF PREPARING HOLOGRAMS comprising

1 methods of producing the various holographic optical elements specified and claimed in
2 Patent '562.

3
4 BRIEF DESCRIPTION OF THE DRAWINGS

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6 The invention will be better understood by the Detailed Description of the
7 Preferred and Alternate Embodiments with reference to the drawings, in which:

8 Figure 1 illustrates the method of magnification that is the basis for both this
9 application and Patent '562.

10 Figure 2 illustrates how a magnified image can be projected before an audience.

11 Figure 3 is a schematic of primary holographic projection using two matrix lens
12 arrays.

13 Figure 4 is a schematic showing the optics of the preferred embodiment of the
14 holographic projector.

15 Figure 5 illustrates how HOLOGRAM #1 in Figure 4 can be prepared.

16 Figure 6 illustrates how HOLOGRAM #2 in Figure 4 can be prepared.

17 Figure 7 is a schematic showing the standard method of image inversion.

18 Figure 8 shows how image inversion can be accomplished without loss of
19 resolution.

20 Figure 9 is a schematic of holographic multiplexing optics.

21 Figure 10 is a schematic showing the method of holographic multiplexing using
22 the optics shown in Figure 9.

1 Figure 11 shows the process for formation or manufacture of the front projection
2 holographic screen.

3 Figure 12 shows the method of reconstruction from projection onto the front
4 projection holographic screen.

5 Figure 13 is a schematic of a primary holographic imaging system using high
6 quality optics.

7 Figure 14 shows the method of fabricating a high quality holographic imaging
8 system.

9 Figure 15 shows how the holographic imaging system of produced using the
10 method of Figure 14 can be used for projection of high quality images.

11 Figure 16 shows the use of a hologram whose reconstructed real image is a 2-
12 dimensional integral photograph.

13 Figure 17 shows a method of preparing strip holograms.

14 Figure 18 shows image inversion from pseudoscopy to orthoscopy using integral
15 photography.

16 Figure 19 shows image inversion from pseudoscopy to orthoscopy using
17 holography and integral photography.

18 Figure 20 shows image inversion from pseudoscopy to orthoscopy using
19 holography.

20

21 DETAILED DESCRIPTION OF THE PREFERRED AND ALTERNATE

22 EMBODIMENTS

23

1 The present invention, in all its embodiments, is based upon a method that
2 permits magnification of a 3-dimensional image produced from a photograph, hologram,
3 optical system or other system or device, regardless of the medium or the method, in such
4 manner as to preserve the depth to height and width relationship of the image as it existed
5 prior to magnification. This method requires the 3-dimensional image prior to
6 magnification to be rendered as an array of 2-dimensional images by some form of matrix
7 lens array, such as a fly's eye lens. Were this array of 2-dimensional images to be
8 magnified by some magnification factor, and then viewed or projected through a new
9 matrix lens array that has been scaled up from the lens array that produced the original
10 array of 2-dimensional images, such that the scaling factor is equal to the magnification
11 (*i.e.*, the focal length and diameter of each lenslet must be multiplied by the same
12 magnification factor), a new 3-dimensional image would be produced that would be
13 magnified by the same magnification factor, and all image dimensions would be
14 magnified by the same factor such that all dimensions of the final 3-dimensional image
15 would be proportional to the dimensions of the original image. The utility of magnifying
16 3-dimensional images using this method would be the ability to enlarge holograms or
17 integral photographs or other media from which 3-dimensional images are produced, or
18 to project still or moving 3-dimensional images before a large audience.

19 The magnification principle is illustrated in Figure 1. Object 1 is photographed
20 by matrix lens array 2, thereby producing integral photograph 3. Integral photograph 3 is
21 then magnified to give integral photograph 4 which is then placed behind matrix lens
22 array 5. This combination yields magnified image 6. It must be noted here, that during
23 scaling-up, the ($F/\#$) of the lenslets remains constant.

1 Projection is merely another form of magnification. The only difference lies in
2 the fact that no permanent record is produced as in photography. To illustrate the
3 principle of projection, let us use as an example, the technique of rear projection shown
4 in Figure 2. (As will be seen later, it is also possible to illustrate this principle with front
5 projection.) Were an integral photographic transparency to be projected at some given
6 magnification onto a translucent screen 7 which is behind a large matrix lens array 8, an
7 observer 9 in the audience sitting in front of the matrix lens array will see the magnified
8 3-dimensional image 10. The 3-dimensional image can be made orthoscopic, and can be
9 made to appear either in front of or behind the matrix lens array.

10 The camera consists of an optical system that would produce the 2-dimensional
11 array of 2-dimensional images on a plane, the plane and/or recording medium whereon
12 the 2-dimensional array is produced, the mechanical apparatus (if any) associated with
13 the image plane and/or recording medium, a means (if any) for adjusting the optical
14 system for focus and/or special effects, and the housing (if any) that integrates the optical
15 system, the mechanical system and the image plane and/or recording medium into a
16 single unit. An example of the optical system is a matrix lens array such as a fly's eye
17 lens arranged so as to produce a rectangular matrix array of rectangular 2-dimensional
18 images. The image plane, for example, would contain a film for recording the 2-
19 dimensional images. Once developed, the matrix array photograph would be called an
20 integral photograph. If the camera is a motion picture camera capable of capturing
21 moving 3-dimensional images in the form of a sequential series of integral photographs, a
22 film motion and film stabilization mechanism would be required. Finally, such a camera

1 might require a housing to integrate the components and to provide a dark environment
2 so as to not expose the film unnecessarily.

3 The projector consists of an optical system that would project a magnified image
4 of the processed 2-dimensional integral photograph produced by the camera onto an
5 image plane that would be converted by the screen into a magnified 3-dimensional image,
6 the mechanical apparatus (if any) associated with the image plane and/or recording
7 medium, a means (if any) for adjusting the optical system for focus and/or special effects,
8 and the housing (if any) that integrates the optical system, the mechanical system and the
9 image plane and/or recording medium into a single unit. If the projector is a motion
10 picture projector capable of magnifying moving 3-dimensional images in the form of a
11 sequential series of integral photographs, a film motion and film stabilization mechanism
12 would be required. Finally, such a projector might require a housing to integrate the
13 components and a projection lamp.

14 The screen consists of an active optical system configured as a matrix lens array
15 comprised of a plurality of optical elements. The screen has the same number of active
16 optical elements as the matrix lens array used in the camera and configured identically as
17 in the camera. In the preferred embodiment of the system, the matrix lens array of the
18 screen is larger than that of the camera such that the ratio of the diameter of the screen
19 lenslets to the diameter of the camera lenslets is equal to the image magnification.
20 However, the $(F/\#)$ of the lenslets in the screen matrix lens array must be equal to the
21 $(F/\#)$ of the lenslets in the camera matrix lens array. Finally, the screen might consist of
22 a mechanism to filter the color of certain portions of the projected image in order to
23 produce a color rendition of a scene projected upon it in black-and-white.

1 Patent '562 describes a number of methods for projecting the photographed scene
2 residing on a 2-dimensional integral photograph or hologram onto a large screen thereby
3 creating a magnified 3-dimensional image of the scene. Many of these utilize complex
4 systems comprised of conventional optics. Conventional optical systems such as those
5 described in Patent '562 are expensive to manufacture, and the images produced
6 therefrom are subject to aberration and distortion. By contrast, holographic imaging
7 devices are inexpensive to manufacture, and images produced from them are generally
8 aberration and distortion free. One method of accomplishing projection using a
9 holographic imaging device is shown in Figure 3. This is the preferred embodiment of
10 the projection system. In this case, instead of using expensive projection lenses, two
11 matrix lens arrays, 11 and 12, are used as shown. On the secondary image plane 14, the
12 image is magnified by the desired amount, and the ratio of the size of the elements of
13 matrix lens array 12 to matrix lens array 11 is equal to the magnification. The hologram
14 is prepared as follows. In the setup shown in Figure 3, replace both the film 13 and the
15 secondary image plane 14 by two diffuser plates. Between the film plane diffuser plate
16 and matrix lens array 11, place a movable aperture which is the size of one element on
17 the film frame 13, and between the secondary image plane and matrix lens array 12, place
18 a similar movable aperture which is the size of a magnified element on the secondary
19 image plane 14. A high resolution photographic plate is positioned in the hologram plane
20 15. The film plane aperture is placed in front of the first elemental position and the
21 secondary image plane aperture is placed in the corresponding first elemental position.
22 Both diffuser plates, 13 and 14, are then trans-illuminated by an appropriate laser for a
23 sufficient time to expose the hologram 15. (This may have to be done for each element

1 by exposing it with many bursts of low intensity laser radiation.) Both apertures are then
2 moved to the second elemental positions and the hologram is exposed again; and so-on
3 for every elemental position. Another method of preparing the same hologram is to also
4 place an appropriate elemental aperture in front of the hologram plane 15. This elemental
5 aperture moves to a different position in front of the hologram plane every time the other
6 two apertures move. The addition of this third aperture will avoid reciprocity problems
7 with the photographic emulsion. (Reciprocity problems will also be avoided by the short-
8 burst method mentioned above. The advantage of the short-burst method over the third
9 aperture method is that crosstalk between elements is avoided.) This method of
10 projection using holographic imaging seems to be the most practical embodiment of the
11 projection principle.

12 Holographic imaging devices can be used with more-or-less standard,
13 inexpensive lenses to accomplish all projection functions. Figure 4 shows the final
14 schematic configuration of this type of projector. This represents the preferred
15 embodiment of the optics of the holographic projector. The image on the film 16 is first
16 magnified onto a secondary image plane 17 holographically using two matrix lens arrays,
17 18 and 19, and the first hologram 20. This magnified image is then used as the reference
18 beam for the second hologram 21 so as to reconstruct a magnified, unmultiplexed,
19 inverted image on the unscrambled image plane 22. This unscrambled image plane can
20 either be an intermediate plane or the screen itself. In the configuration shown, it is an
21 intermediate plane, and a position adjustable projection lens 23 is used to project the
22 image formed at this plane onto the screen. No diffuser plates are needed at the
23 intermediate image planes (although they can be used if necessity dictates), and their use

is undesirable since they add greatly to the required illumination levels. The first and second holograms, 20 and 21, are shown in the figure as volume or reflection holograms. Transmission holograms can also be used, but the efficiency of transmission holograms is less than reflection holograms. Therefore, using transmission holograms would also add to the required illumination levels. The only non-holographic optical elements in the projector are either simple projection lenses or matrix lens arrays. Therefore, the holographic projector represents a far simpler system than the projector using more conventional optics.

Figure 5 illustrates how the first hologram 20 in Figure 4 can be produced. Two active optical systems are used to produce the reference and object beams necessary to expose the photographic plate to produce the reflection hologram. The first active optical system is comprised of a diffuser plate 24 and the first matrix lens array 25. When illuminated by coherent light, the diffuser plate 24 scatters the light which is still coherent, and the scattered light impinges upon the matrix lens array 25 which, in turn, produces the reference beam 26. The second active optical system is comprised of a diffuser plate 27 and the second matrix lens array 28. When illuminated by coherent light coming from the same source as that which illuminated the first active optical system, the diffuser plate 27 scatters the light which is still coherent, and the scattered light impinges upon the matrix lens array 28 which, in turn produces the object beam 29. The reference beam 26 and the object beam 29 impinge upon opposite sides of the unexposed transparent photographic plate 30. This photographic plate, when developed and processed, becomes the first hologram 20 of Figure 4. It should be noted that, with a hologram of this type, it is possible, and it might be desirable to eliminate the second

1 matrix lens array 19 from the projection optics of Figure 4, while producing the same
2 result.

3 Figure 3 shows a optical system consisting of more than one hologram.
4 Holograms can be used as imaging devices in the camera as well as in the projector. One
5 of the tasks of holographic optical systems is to perform multiplexing and
6 unmultiplexing. Multiplexing is the process of optically compressing the elemental
7 images of an integral photograph and then scrambling their relative positions so as to
8 enable them to fit into a small space on the image plane. In a camera, the image plane
9 would normally contain photographic film, but the medium could be something else such
10 as image orthocon tubes. Unmultiplexing is the reverse process of expansion and
11 unscrambling the images from the multiplexed image plane and projecting it onto a
12 second image plane so that the image becomes a readable integral photograph.
13 Multiplexing must be performed by the camera while unmultiplexing must be performed
14 by the projector.

15 Another task that can be performed by a holographic optical system is the
16 conversion of the final 3-dimensional image from pseudoscopy to orthoscopy. A viewing
17 audience expects to see an orthoscopic 3-dimensional image of a scene. Orthoscopy
18 occurs normally where a first object that is supposed to be in front of a second object
19 appears closer to the viewer. Pseudoscopy occurs where the second object appears closer
20 to the viewer. This is an unnatural viewing condition that would be annoying to an
21 audience. Unfortunately, the image produced using the basic principle of magnification
22 and projection is pseudoscopic. Therefore, optics must be used to convert from
23 pseudoscopy to orthoscopy.

1 In Patent '562, the most practical method and the preferred embodiment of
2 unmultiplexing is with the use of a holographic imaging device. Not only can the entire
3 image unmultiplexing process be accomplished in one step using such an element, but so
4 also can both the inversion of the image from pseudoscopy to orthoscopy and the final
5 projection (if these steps are desired to be performed using this method). The use of this
6 method is shown in Figure 6. The magnified image from the secondary image plane 31 is
7 projected onto a specially prepared hologram 32, using a standard projection lens 33.
8 The hologram is so designed that when illuminated with such a reference beam, it will
9 generate an object beam which when projected through a second projection lens 34, will
10 image onto another plane a picture having the vertical rows arranged side-by-side
11 horizontally 35. The hologram used here is similar to the second hologram, 21, in Figure
12 4. (It is highly desirable to replace the projection lenses by two matrix lens arrays as is
13 shown in figure 3. This is also illustrated as the first hologram, 20, in Figure 4.) The
14 method to fabricate such a hologram can be illustrated using Figure 6. Replace the
15 secondary and unscrambled image planes (31 and 35 respectively) by diffusing screens.
16 Apertures must be used with both reference and object beams so as to direct the location,
17 size and shape of each corresponding row between the secondary and unscrambled image
18 planes. This holographic imaging device is then fabricated by the same method as that
19 which is shown in Figure 5 as previously described. (This is not to say that the
20 holographic imaging device described here is the same as previously described and
21 illustrated in Figure 5, but only that it is fabricated in a similar manner.) Similarly, as
22 with the previous holographic imaging device, an aperture could be used with the

1 photographic plate to solve the problem of emulsion reciprocity, or the short-burst
2 method can be used.

3 The method of inverting a pseudoscopic image is to reconstruct the 3-
4 dimensional image in the usual manner and then to re-photograph the reconstruction with
5 a second camera. The reconstruction of this second film will produce a pseudoscopic
6 image of the 3-dimensional image which was photographed. Since, this image was
7 originally pseudoscopic, the pseudoscopic reconstruction of this image would be
8 orthoscopic. This method of image inversion is shown in Figure 7. This technique has
9 two major disadvantages. First, an intermediate processing step is required in which a
10 second film must be made; second, there is an inherent resolution loss of $\sqrt{2}$ when going
11 from one film to the other.

12 There is another basic method of producing orthoscopic images from
13 pseudoscopic images which will not incur this resolution loss. This method was
14 described in Patent '562. The basic principle is quite simple. Referring to Figure 8, if the
15 film format shown in Figure 8 (a) produces a pseudoscopic image, then it can be shown
16 by an optical analysis of what a second film record would look like were the 3-
17 dimensional image from Figure 8 (a) to be photographed, that the film format of Figure 8
18 (b) would produce an orthoscopic mirror image of the pseudoscopic 3-dimensional image
19 produced by the format of Figure 8 (a), while format of Figure 8 (c) will produce a
20 correct orthoscopic image.

21 The method for image inversion discussed here concerns itself only with its
22 performance in the projector. Any intermediate processing where another film must be
23 prepared is discussed in Patent '562 only. The proposed method is to perform this

1 inversion during unmultiplexing when a holographic imaging device is used (refer to
2 Figure 3). In this case, each element would be mirror image inverted, but the order of the
3 elements could be kept in-tact holographically. In fact, the elements can be
4 holographically arranged in any order that is desired.

5 Accordingly, any of the holographic optical elements described above can be
6 fabricated in a manner so that when an integral photographic image is processed by it, the
7 3-dimensional image projected therefrom will be orthoscopic. This is done by optically
8 reversing each elemental image of the integral photograph separately as shown in Figure
9 8. When preparing the elemental parts of the holographic imaging device, the optics for
10 elemental image inversion must be included.

11 Therefore, the schematic shown in Figure 4, either including or not including the
12 second matrix lens array 19, represents the ideal optical system for projection and
13 magnification of integral photographs. Not only do the holograms cause projection and
14 magnification of the integral photographs on the screen, but they also unmultiplex the
15 unmagnified integral photograph and perform the appropriate image inversion required
16 for ultimate viewing of the resultant 3-dimensional scene.

17 Now turning to the issue of image multiplexing, Patent '562 describes one
18 embodiment of the camera design that uses holographic optics to accomplish the image
19 dissection and multiplexing. This is shown conceptually in Figure 9. In this case,
20 reflection holograms are used because of their high diffraction efficiency (95-100%),
21 although the process would work conceptually even with transmission holograms. (The
22 diagrams, however, are shown using reflection holograms.) This process involves the
23 transfer of images from one holographic plane to another plane with 1:1 magnification.

1 (Several methods exist to provide aberration free magnification using holography, should
2 this be desirable.) In the figure, the image 36 is projected through the camera matrix lens
3 array 37 or otherwise focused onto hologram plane 38 which, in turn, projects the
4 appropriate multiplexed frame onto the film, 39, using intermediate holographic planes
5 (shown symbolically as planes 40) if necessary. These intermediate planes serve the
6 purpose of allowing the image to impinge onto the film from a far less severe angle,
7 thereby decreasing the aberrations. But, these intermediate planes may not be necessary.
8 Figure 10 shows conceptually how such a holographic plane can be made. For clarity,
9 multiplexing will be accomplished, in this figure, for only two rows. The image on the
10 left with two rows, 41 and 42, arranged horizontally is projected using lens 43 onto
11 hologram 44. This projected image acts as a reference beam for the hologram, therefore,
12 reconstructing an object beam which focuses an image in space 45, consisting of rows 41
13 and 42 arranged vertically. The hologram is prepared by using two moving apertures.
14 The hologram is prepared using each elemental image of the primary integral photograph
15 as the reference beam and the corresponding elemental image of the secondary integral
16 photograph as the object beam and by exposing the photographic plate with both
17 reference and object beams on opposite sides. The apertures then move to each pair of
18 elemental images in turn, with the hologram being re-exposed each time. It could be
19 desirable to use a third moving aperture and fourth moving aperture positioned adjacent
20 to but on opposite sides of the photographic plate. Furthermore, it could be desirable to
21 use coherent light from a short burst laser to expose the photographic plate so as to
22 reduce noise.

1 The preferred embodiment of the screen is an array of cylindrical zone plates
2 with associated color filtration. Zone plates can be produced holographically. However,
3 instead of being produced as transmission holograms, they are produced as reflection
4 holograms. Reflection holograms are commonly manufactured by a process called
5 Bragg-Angle Holography. In this instance, instead of the diffraction pattern being
6 formed on the surface of the photographic emulsion which makes up the hologram, the
7 diffraction pattern is formed in the volume of the emulsion itself. Such a holographic
8 zone plate would have the following advantages:

- 9 (1) Since it is formed as a reflection hologram, this type of screen is applicable to
10 front projection, the technique now in use in most theaters.
- 11 (2) A reflection holographic screen accepts white light emanating from a point
12 source and reflects it into the audience at the wavelength with which the holo-
13 gram was initially made. Since the zone plate screen consists of a mosaic of al-
14 ternating zone plates, each one produced as a hologram by laser light having a
15 different wavelength, it becomes obvious that a holographic screen of this type
16 already has its own color plate "built-in". Separate color filters are not required.

17 The screen is a Bragg Angle Reflection Hologram, which when illuminated from
18 the front with a beam of white light having a spherical wavefront, the reconstruction will
19 be a series of thin vertical lines, each line a different color, the colors alternating between
20 red, green and blue, each line projected in front of the screen a distance f , and the vertical
21 lines will be arranged horizontally across the width of the screen. A Bragg Angle
22 Hologram is really a diffraction grating whose diffracting elements are distributed
23 throughout the volume of the emulsion. A reconstruction can only be obtained by a ref-

1 erence beam of the same wavelength as was used to make the hologram. For this wave-
2 length, the reconstruction efficiency is extremely high. If a white light reference beam
3 should be used, only the appropriate color component will be selected to perform the re-
4 construction.

5 Figure 11 (a) shows the fabrication of a reflection hologram with monochromatic
6 light. The reference beam is a spherical wavefront and the reconstruction is a real image
7 of a single vertical line projected in front of the hologram. The object beam is created by
8 passing a laser beam 46 through a cylindrical lens 47 which focuses through a slit 48
9 positioned at a distance f from the photographic plate 49. The reference beam is
10 produced as a spherical wavefront from the same laser 46, and is made to impinge upon
11 the opposite side of the photographic plate 49. This operation can be performed
12 separately for each wavelength needed, or the hologram can be fabricated as shown in
13 Figure 11 (b). A white light, or multi-wavelength laser 50, such as a krypton laser, is
14 used. The complete beam having all color components is used as the reference beam 54.
15 The laser beam is split in two using a beam splitter 51 into two components 52 and 53.
16 Beam 52 ultimately becomes the reference beam 54 after passing the optical components
17 (mirrors M_1 , M_2 and M_3 , and concave lens L_1 and circular aperture S_1). Beam 53
18 ultimately becomes the object beams. First, the color components are separated by a
19 prism 55. The unwanted wavelength components are removed by mirrors M_0 and M_3
20 leaving only the three red 56, green 57 and blue 58 object beams to be used to create the
21 hologram. (Of course, colors other than red, green and blue can be used as long as they
22 are complementary colors which are used to form white.) Thus far only three zone plates
23 have been created on the photographic plate 59. The photographic plate 59 is then

1 moved, and a new section is exposed in exactly the same manner. The method of recon-
2 struction is shown in Figure 12. A white light reference beam with a spherical wavefront
3 is used to reconstruct alternating red, green and blue cylindrical wavefronts. Should the
4 reference beam emanate from a projector in the rear of the theater with the image of an
5 integral photograph impressed on the beam such that the image of the integral photograph
6 is focused onto the screen, then a 3-dimensional image will be reconstructed from the
7 integral photograph. In this case, a color filter is not required, as the image will be
8 properly broken down into the appropriate color pattern, and black & white film must be
9 used.

10 The screen need not be prepared as an extremely large hologram, as this would
11 be impractical. Even in a very small theater, the screen size might be 20 feet wide \times 10
12 feet high. The mechanics of producing a hologram that large is formidable. Instead,
13 smaller rectangular shaped tiles can be produced which are all identical. These tiles can
14 then be assembled to produce a screen of any size.

15 Now we turn to the fabrication of high quality holographic imaging optics. With
16 any ordinary optical system, when projecting a 2-dimensional image, the projected image
17 is normally degraded with respect to the original image. This is true even at 1:1
18 magnification. The reason for this is that most optical systems exhibit inherent
19 aberration and distortion. However, it is often required that a projected image have
20 extremely high quality with minimum aberration and distortion. To accomplish this,
21 special high quality optical systems must be used. Often such optics do not exist, and
22 must be specially designed and fabricated. Obtaining such optics can be very expensive.

1 Patent '562 discloses the requirement that projected images must be of extremely
2 high quality, particularly during intermediate processing and intermediate projection. A
3 special case of this intermediate projection is when it is performed at no magnification.
4 This is very useful in certain of the final projection systems discussed in Patent '562.
5 What is required is that an image be transferred from one image plane to another at 1:1
6 magnification with the resolution preserved, *i.e.*, the total information must be transferred
7 from one image to the other. Such an imaging system is typically used for a
8 microprojector and semiconductor circuits. One such system was designed by PERKIN-
9 ELMER several years ago. This optical system uses mirrors instead of lenses. It covers a
10 field of two-inches. Resolution was one-micron or 500 line pairs/mm. Of course such an
11 optical system could be constructed using lenses, but it would be more complex and very
12 much more expensive.

13 Holographic optics can be used to accomplish this type of high quality image
14 transfer or projection. Reflection holography should definitely be used since the
15 diffraction efficiency is much higher than for transmission holography. Figure 13 shows
16 how a non-permanent image can be projected using the principle of primary holographic
17 projection. The 2-dimensional image from the film 60 is projected onto a reflection
18 hologram 61 using a 1:1 imaging optical system 62. The image is then focused onto a
19 secondary image plane 63. In this case, a specially designed aberration free lens 64 is
20 used in conjunction with the hologram for projection. Since this expensive lens must be
21 used during normal projection of the film, this method is not very practical. However,
22 since a hologram is an imaging device itself, the hologram can be used as a high quality
23 lens.

1 Figure 14 shows one method of fabricating such a hologram. The film 60 of
2 Figure 13 is replaced by a translucent diffusing screen, and another translucent diffusing
3 screen is made to coincide with the secondary image plane 63 of Figure 13. In this case
4 the photographic plate is totally reflective on the side opposite from the emulsion. Both
5 diffusing screens are trans-illuminated by the same laser and the hologram is exposed.
6 The reference beam passes through the standard lens while the object beam passes
7 through the high quality lens. Of course, this can also be accomplished by eliminating
8 the reflective coating on the reverse side of the photographic plate by causing the object
9 beam to impinge upon the reverse side of the plate. However, the efficiency of the
10 reflective method is considerably higher.

11 Figure 15 illustrates how such a hologram would be used. A standard projection
12 lens 65 images the film frame 66 onto the specially prepared hologram 67, which, in turn,
13 acts as a reflecting lens to image the film frame onto the secondary image plane 68 at
14 some greater magnification. This hologram is a high quality Leith Hologram, and is
15 indicated operating as a reflection hologram because the diffraction efficiency is much
16 higher for reflection than for transmission.

17 The discussion now proceeds to holography of a 2-dimensional integral
18 photographic film. In this method a holographic movie film is used. However, the
19 projected real image of the hologram is a 2-dimensional image which is projected onto a
20 diffusing screen (or imaginary image plane). This image is the integral photograph to be
21 projected. This process is illustrated in Figure 16. Since the initial photograph that will
22 be taken by the camera is an integral photograph, a hologram can be taken of each frame
23 of the integral photographic film, and the reconstructed image will, therefore, be the

1 integral photograph. Referring to Figure 16, to construct the hologram 69, a laser beam
2 70 passing through a standard projection lens 71 serves as the reference beam. The
3 integral photographic frame is projected using the same laser beam onto diffusing screen
4 73 which produces the object beam 74. The combination of reference beam 72 and
5 object beam 74 produces the hologram. To reverse the process for projection, light
6 impinges upon projection lens 71 and then upon the holographic film frame 69. This
7 reconstructs object beam 74 that produces a focused image of the integral photograph on
8 diffusing screen 73. This method contrasts with that of direct holography where
9 holograms are taken of the scene directly.

10 In 1968, Dr. D. J. DeBitetto of Phillips Laboratories, Briarcliff Manor, NY,
11 published several articles concerning holographic 3-dimensional movies with constant
12 velocity film transport. In these articles, he described holograms produced which
13 allowed bandwidth reduction by elimination of vertical parallax. This was accomplished
14 by making the 3-dimensional holograms on a film strip using a horizontal slit as an ap-
15 erture. The frames were formed by advancing the film each time by the width of the slit.
16 Each frame was animated. After development, the film was illuminated as any hologram
17 would be, and the filmstrip was moved at constant velocity. I have seen Dr. DeBitetto's
18 holographic movies, and they are the best attempts to-date in the field of motion picture
19 holography. The 3-dimensional pictures are of extremely high quality. However,
20 vertical parallax was absent.

21 The same technique can be used in our projector. It can be used with direct
22 holography as Dr. DeBitetto did or it can be used with holograms of integral photographs
23 as shown in Figure 17. In this figure, and by this technique, a horizontal strip hologram

1 75 is taken of each integral photographic frame 76 (in any format, multiplexed or
2 unmultiplexed), and the holographic film strip is advanced for each frame. This is done
3 by projecting the integral photographic frame 76 onto a diffuser plate 77 using coherent
4 illumination from a multicolor laser 78 (e.g., a white light krypton laser). This becomes
5 the object beam necessary to produce the hologram. It is possible to take several strip
6 holograms of the same frame. Afterwards, the holographic film 79 is played back in the
7 projector at constant velocity.

8 Dr. DeBitetto takes his holograms as strip holograms in that both the holography
9 and projection must be performed with the slit aperture. This requires the holography of
10 a very large number of small strip frames, the animation of each frame showing only
11 slight or minuscule motion with respect to the previous frame. This is contrasted with the
12 method of taking holographic movies where each frame has a reasonable size both in
13 height and in width (as would be expected in a standard format motion picture film).
14 Obviously, Dr. DeBitetto's technique has the disadvantage of requiring an extremely
15 large number of frames, thus making the process very arduous. However, this patent
16 application submits that the frames be prepared in the standard motion picture format (as
17 opposed to horizontal strip holograms), and that the frame be projected with a horizontal
18 slit aperture. The film is used in the same way as in Dr. DeBitetto's process, and is
19 projected at constant velocity. The image projected from the hologram onto the screen
20 will only change in vertical parallax as the frame moves by the aperture. However if the
21 film format used is that previously described for holography of the original 2-dimensional
22 integral photographic film, then the vertical parallax does not change as the frame moves
23 by, because the projected image is 2-dimensional and has no vertical (nor horizontal)

1 parallax. The image only changes, therefore, when a new frame comes into view.
2 Therefore, the height of the frame required for the holographic film will depend upon the
3 film velocity and the frame rate. This represents the preferred embodiment for the
4 holographic projector.

5 Constant velocity is a tremendous advantage for projection of 3-dimensional
6 movies. Since film registration must be held to extremely tight tolerances, not having to
7 stop the film for each frame would provide much needed stability, and film registration
8 would be far simpler. Without this constant velocity transport, each frame would have to
9 be registered with the three-point registration system as described in Patent '562.
10 Furthermore, constant velocity film transport reduces the probability of film breakage.

11 The discussion now turns to intermediate processing of the film. In the previous
12 discussions of the formation of orthoscopic images from pseudoscopic images, image
13 inversion was accomplished during the projection stage. It is considered more desirable
14 to accomplish this operation during the projection stage because it can be done without
15 the inherent loss in resolution (a factor of $\sqrt{2}$) attached to a process in which a new
16 integral photograph or hologram must be copied from the 3-dimensional projected image.
17 Should it be desired to make a film to be presented to motion picture theaters, which, in
18 turn, when projected, would produce orthoscopic images, then the best method of making
19 such films from the original would be by the projection techniques previously discussed.
20 These projection techniques can be used for film copying as well as for projection onto a
21 screen. However, for the sake of completeness of this application, the methods for image
22 inversion, by making a new integral photograph or hologram from the original
23 reconstructed 3-dimensional pseudoscopic image, will be presented.

1 Figures 18, 19 and 20 show how to perform this inversion. Figure 18 illustrates
2 converting from one integral photograph to another; Figure 19, from an integral
3 photograph to a hologram; and Figure 20, from one hologram to another. Note that, in
4 each of these setups the film upon which the new integral photograph or hologram is to
5 be produced may be positioned anywhere with respect to the pseudoscopic image. What
6 is important is that the original reconstructed wavefronts be used to form the new record
7 and not the image.

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